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Effects of Carbon Dioxide on Combustion of Methane/Hydrogen in a Swirl Combustor

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ABSTRACT

Effects of adding carbon dioxide on methane/hydrogen combustion are numerically studied in a swirl burner. Mole fractions of carbon dioxide and nitrogen monoxide at the exhaust were analyzed using different carbon dioxide blends ranging from 0-25% in CO_2/air mixtures. A simulation was carried out by using SST k-ω turbulence model and finite rate chemistry model with flamelet concept included. Calculations using a detailed chemical kinetic scheme to predict the emission characteristics were also attempted to determine concentration values more accurately. Results show that by adding carbon dioxide to air significant reduction in CO_2 and NO emissions can be achieved, whereas temperature of the flame also decreased. The results can provide information for emission reduction of gas turbines, saving costs of later post-treatments.

Keywords:

1. INTRODUCTION

With the rapid economic development of human society, various energy problems and environmental problems have emerged. At the same time, as people pay more attention to environmental issues, the requirements for environmental protection and ecology are becoming increasingly strict. Among all kinds of environmental problems, global climate change is the most widely concerning by the international community. To date, the rate of global warming is gradually accelerating. Among all kinds of greenhouse gases in the atmosphere, CO_2 has the highest content and long life, and contributes the most to the greenhouse effect. In order to control greenhouse gas emissions and protect civilization from the threat of climate warming, the most direct way to deal with the current greenhouse effect is to optimize the energy structure and vigorously develop the natural gas industry and effectively reduce CO_2 emissions from high-carbon fossil fuels by applying carbon capture related technologies [1]. A method under scrutiny is exhaust gas recirculation.

Combustion with air separation/flue gas recirculation technology begins with the treatment of CO_2 [2]. This technology uses oxygen-rich air with a higher oxygen concentration than conventional air for combustion. The process controls the oxidizer component ratio by adjusting the ratio of combustion air and circulating flue gas to meet different combustion requirements. The flue gas recirculation technology has been applied to natural gas combustion, which is a new emission reduction technology with high efficiency and energy saving features. It has the advantages of enabling high CO_2 capture, thus reducing CO_2 emissions, lowering costs of recovery, and ensuring high desulfurization rates. The concept has a good application prospect for energy conservation and emission reduction. The research of flue gas recirculation technology has attracted vast global attention due to its potential carbon emission reduction features. At present, flue gas recirculation technology has become mature in static experiments, and has been explored and applied in fluidized beds, boiler combustion, industrial furnaces, engines and other industries. In the near future, China will accelerate the pace of research and development of flue gas recirculation technology, focusing on boilers, burner technology, flue gas purification technology, flue gas condensation technology and system integration, so as to gradually master the technology [3, 4].

Therefore, and advancing on the subject, the present work shows a numerical simulation performed to study the effects of adding carbon dioxide on methane/hydrogen combustion in a swirl burner. Temperature, carbon dioxide and nitrogen monoxide concentrations at the exhaust are analyzed using a turbulent combustion model with a detailed chemical kinetic scheme to predict emission characteristics.

2. MODELLING FOR THE SWIRL COMBUSTOR

SST k-ω turbulence model is chosen due to its applicability in swirl combustion studies. The implementation of turbulent combustion is carried out by using finite rate chemistry models of steady flamelet. Finite rate chemistry models solve the equations by using a model of reaction rates and a detailed mechanism. The flamelet concept is included in this model which considers that the turbulent flame is composed of laminar, thin and one dimensional flamelet structures. For example, counterflow diffusion flames can be used to represent a turbulent flow. The steady flamelet model assumes that the flamelet lifetime is much longer than the characteristic time scale of the related phenomena, therefore it considers transient effects negligible. The kinetic mechanism is essential through the simulation. A detailed chemical mechanism of GRI 3.0 is used which has been widely employed in methane combustion studies. By using the meshing tools in ANSYS, an unstructured mesh containing 0.3 million nodes is generated for the simulation of a swirl combustor, figure 1.

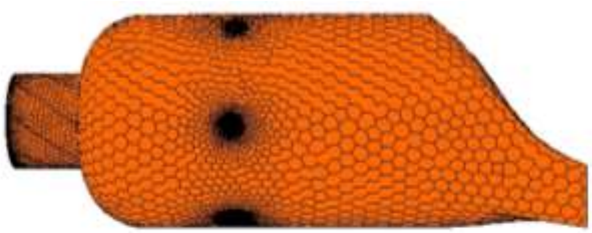

Fig.1 Mesh of the combustor

The burner used in the present work has a injector with one main inlet and six fuel inlets separately. The fuel mixture used is 90%CH4-10%H2, which represents natural gas mixed with hydrogen fuels. The fuel mixture is then injected into the burner at a speed of 40 m/s through fuel inlets. The primary air enters the chamber through swirl blades at a speed of 10 m/s at the bottom of the burner. The air entering the burner promotes its mixing with the fuel to achieve a good grade of mixing before combustion. The downstream secondary air enters the combustion chamber at a speed of 6 m/s through secondary air inlets. Normal temperature and pressure conditions are used in the simulation.

3. RESULTS AND DISCUSSION

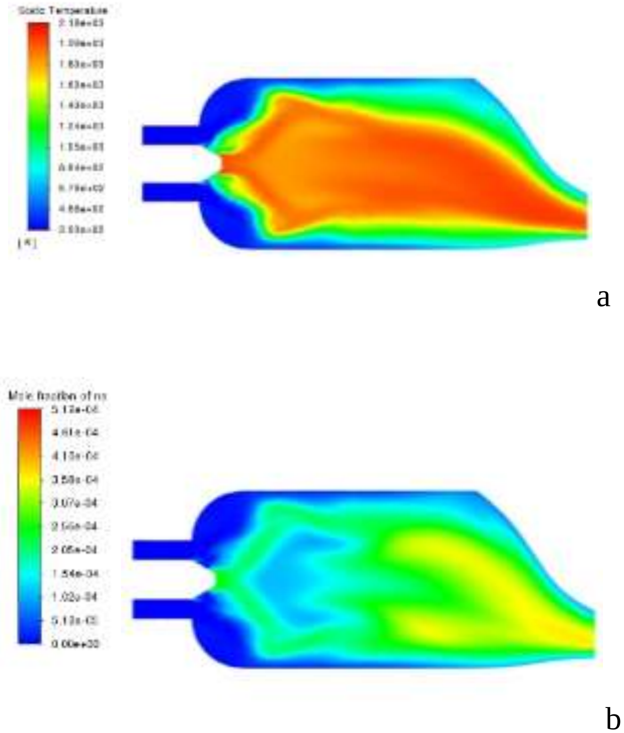

Fig.2 Temperature field and NO mole fraction in the burner using air

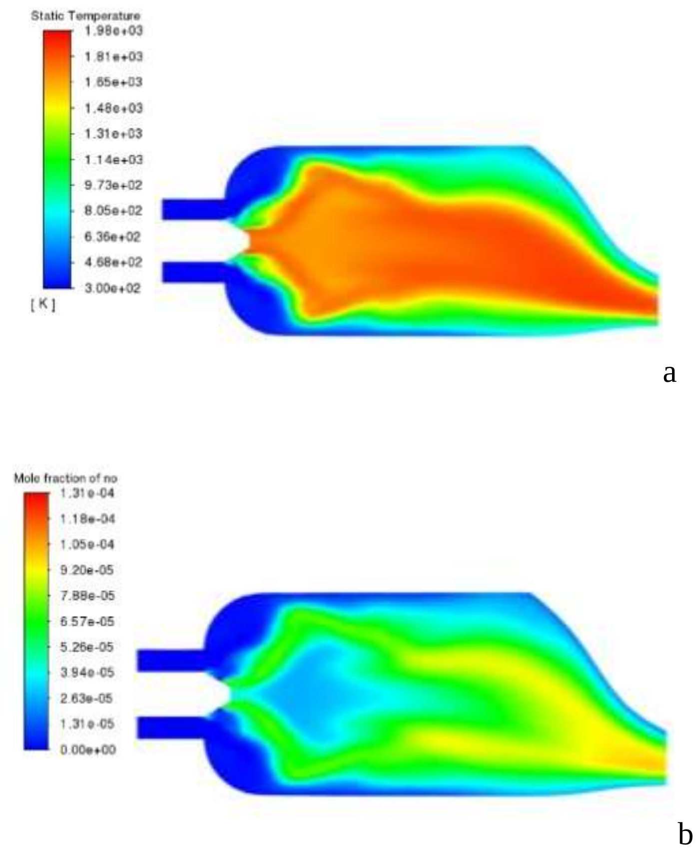

Fig.3 Temperature field and NO mole fraction in the burner using 5% CO_2 in air/ CO_2

Results provided an overview of the entire field and progression of temperature and species, Figs. 5 to 8. As the swirling flow acted on the combustion process, a central recirculation zone was observed in the center of the burner with relatively lower temperature. Comparing the two figures, obvious decrease in temperature and NO emission is found when small amount CO_2 added into the air. In addition, as can be observed in the combustor, the formation of NO emissions mainly takes place at the boundaries of the flame, resulting from the high temperatures of combustion and recombination of species.

Different parameters of the outlet are compared under different CO_2 concentration conditions as show in figures 6-8. NOx emissions are one of the essential concerns in combustion technology. Since NO concentration in the process is much higher than N_2O and NO_2, NO is used to represent the NOx emission in the following discussions. As shown in fig. 6, with the addition of CO_2 in the primary air inlet, NOx emissions drop sharply. However, this effect becomes of lesser impact at higher CO_2 concentration conditions. It is believed that by increasing the content of CO_2 into air will lead to lower flame temperature which subsequently leads to the reduction of thermal NOx emission. This also indicates that the CO_2 addition has a big influence on the emission characteristics in gas turbine combustors, suggesting higher CO_2 fraction in the fuel mixture can have advantages in NOx emission reduction. These numerical results will help design the proper oxidizer mixture for gas turbine combustors.

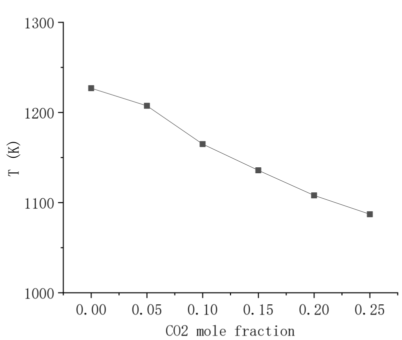

Fig.4 Average temperature at outlet against CO_2 mole fraction in CO_2/air

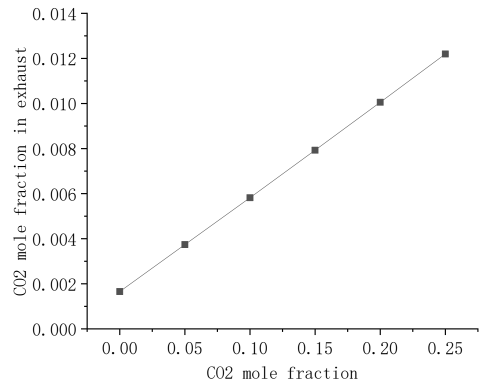

Fig.5 Average CO_2 mole fraction in exhaust against CO_2 mole fraction in CO_2/air

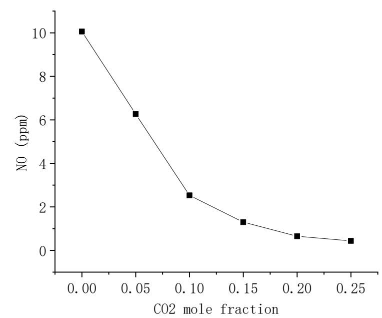

Fig.6 Average NO mole fraction in exhaust against CO_2 mole fraction in CO_2/air CO_2

4. CONCLUSIONS

A 3D simulation of turbulent combustion for methane/hydrogen was carried out with complex chemistry investigating the effects of carbon dioxide addition on the combustion of methane/hydrogen blends in a swirl burner. Results showed that the temperature of the flame in the swirl burner will decrease with CO_2 addition. NOx emissions production also drop significantly with the addition of CO_2 in the air, indicating that the CO_2 addition can have a big influence on emission characteristics of the swirl combustor. Further experimental and numerical studies need to be performed to have a deep insight into the effect of CO_2 addition on methane/hydrogen combustion.

ACKNOWLEDGEMENT

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